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Anomalous tqg and tqH couplings effects in a Top-Higgs Final State

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Abstract

We study the anomalous production of a single top quark in association with a Higgs boson at the LHC originating from flavor-changing neutral current interactions in tqg and tqH vertices. We derive the discovery potentials and 68% C.L. upper limits considering leptonic decay of the top quark and the Higgs boson decay into a $b\bar{b}$ pair with 10 fb^{-1} integrated luminosity of data at 14 TeV. We propose a charge ratio for the lepton in top quark decay in terms of lepton p_T and η as a strong tool to observe the signal.

Keywords: Top Quark, Higgs Boson, Flavor-Changing Neutral Current

1. Introduction

Because of large top quark Yukawa coupling, the top quark properties could be studied in channels where a Higgs boson is also present. Flavor-Changing Neutral Current (FCNC) couplings for top quark are forcefully suppressed within the Standard Model (SM) by Glashow-Iliopoulos-Maiani (GIM) mechanism. However, there are many extended standard theories which predict sizeable top quark FCNC couplings. The anomalous FCNC interaction tqg and tqH could be described by model independent effective Lagrangian as the following [2]:

$$\begin{aligned} \mathcal{L} &= \sqrt{2}g_s \sum_{q=u,c} \frac{\kappa_{tqg}}{\Lambda} \bar{t}\sigma^{\mu\nu}T_a(f_q^L P_L + f_q^R P_R)qG^a_{\mu\nu} \\ &+ \frac{g}{2\sqrt{2}} \sum_{q=u,c} g_{tqH}\bar{q}(g^v_{tqH} + g^a_{tqH}\gamma_5)tH, \qquad (1) \end{aligned}$$

Where Λ is the energy scale of new physics. κ_{tqg} and g_{tqH} (with $q = u, c$) are real dimensionless parameters. $f_q^{L(R)}$ and $g^{v(a)}_{tqH}$ are the parameters which define the chirality.
In this paper, we consider the production of a single top quark in association with a Higgs boson for probing tqg and tqH anomalous couplings. We assume leptonic decay of the top quark and Higgs decays into b and $\bar{b}$. Therefore, there are one charged lepton (electron or muon), a missing energy and three b jets in the final state. The Analysis is performed for the LHC with 10 fb^{-1} of integrated luminosity of data at center-of-mass energy of 14 TeV. The representative Feynman diagram of the signal process including the decay chain is shown in Fig.1.

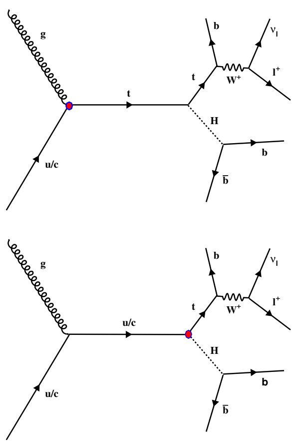

Figure 1: Feynman diagram for production of a top quark in association with a Higgs boson.

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2. Event Simulation and Selection

According to the final state of the signal, main backgrounds are $Wb\bar{b}j$, $Wjjj$, WZj, and $t\bar{t}$. For the sake of simulating the signal events, the effective Lagrangian has been implemented within the FeynRules package then inserted into the MadGraph 5 package. For generating events for signal and backgrounds at parton level, MadGraph 5 package [3] has been employed with the cteq6 [4] as the proton PDF then for parton showering Pythia 8 has been used. [5]. FastJet package [6] accomplishes jet reconstruction with the cone size of $R = 0.4$. A b-tagging efficiency is considered 60% for b-jets and a mis-tagging rate is assumed 10% for other quarks. The effects of detector resolution are simulated through Gaussian energy smearing which is applied to jets and leptons with a standard deviation parameterized according to the following:

$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus b \tag{2}$$

For resolutions of jets (leptons) we take the values of ATLAS detector, $a = 0.5(0.1)$ and $b = 0.03(0.007)$. We apply basic cuts on the final state objects. Charged lepton and jets p_T cut is required to be greater than 25 GeV within the pseudorapidity range of $|\eta| < 2.5$. The missing transverse energy should be greater than 25 GeV. The angular distance between each two objects should be larger than 0.4. For top quark reconstruction, we need to have the full momentum of the neutrino which is found by using $W-$boson mass constraint. Two solutions are obtained which gives us two neutrinos. The combination of the charged lepton, two neutrinos and three b-jets leads six different top quarks. Among all of these combinations we choose the one which has closest mass to the nominal top quark mass. After that with two remaining b-jets, we reconstruct Higgs boson. For suppressing the backgrounds, we look at some kinematic distributions. To reduce the background contributions, we reject events with $|m_{H,rec} - 125| > 15$ GeV and $p_{T,Higgs} < 100$ GeV. Also to enhance the signal contribution, we require the events with $|y_l - y_H| < 1.2$ and $|y_H| > 0.8$. In Fig.2, we show the reconstructed top quark mass after all cuts for signal and backgrounds with 10 fb^{-1} of integrated luminosity and with $\kappa_{tug}/\Lambda = 0.1$ TeV^{-1}. It can be seen that top quark has been reconstructed well.

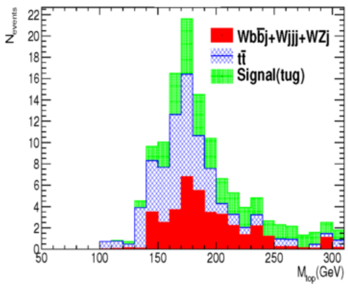


Figure 2: The reconstructed top mass distribution after all selection for 10 fb^{-1} of LHC at 14 TeV center-of-mass energy for the signal with $\kappa_{tug}/\Lambda = 0.1$ TeV^{-1} and backgrounds.

3. Results

As mentioned before, the $t + Higgs$ final state can arise from both tqg and tqH anomalous couplings. In the presence of both couplings cross section could be parameterised as:

$$\begin{aligned} \sigma(\frac{\kappa_{tqg}}{\Lambda}, g_{tqH})[pb] &= c_{tqg} \times (\frac{\kappa_{tqg}}{\Lambda})^2 + c_{tqH} \times g^2_{tqH} \\ &+ c_{int.} \times \frac{\kappa_{tqg}}{\Lambda} \times g_{tqH}. \end{aligned} \tag{3}$$

After the besic cuts, the coefficients are $c_{tu(c)g} = 5.6(1.05)$, $c_{tu(c)H} = 0.09(0.01)$, and $c_{int.} = 0.46(0.2)$. The contribution of tqg couplings is larger than tqH in the cross section of signal. After applying all cuts we calculate the 3σ and 5σ discovery. Figure 3 shows the 3σ exclusion regions using 10 fb^{-1} of the integrated luminosity at 14 TeV. In case of finding no evidence for signal, we can set upper limits on the anomalous couplings. We choose distribution of $|y_l - y_H|$ for a shape analysis, because the shape of signal and background are different in this distribution [1]. The χ^2 criterion is defined as:

$$\chi^2(\frac{\kappa_{u,c}}{\Lambda}) = \sum_{i=bins} \frac{(s_i - b_i)^2}{\Delta_i^2}, \tag{4}$$

where s_i and b_i denotes the number of signal and background events in the i-th bin, respectively. Δ_i is defined as $b_i \sqrt{\delta^2_{stat} + \delta^2_{syst}}$. Where δ_{stat} and δ_{syst} are the statistical and systematic uncertainties, respectively. We take into account 10% for systematic uncertainty. The number of signal events depend on the anomalous couplings of $\kappa_{u,c}/\Lambda$. So, the 68% C.L. upper limits on the anomalous FCNC couplings are found to be:

$$\frac{\kappa_{tug}}{\Lambda} \leq 0.014\, TeV^{-1}, \; \frac{\kappa_{tcg}}{\Lambda} \leq 0.045\, TeV^{-1}. \tag{5}$$

4. Charge Ratio

One of the interesting features of the signal ($g + u(\bar{u}) \to t(\bar{t}) + H$), is the asymmetry between top and anti-

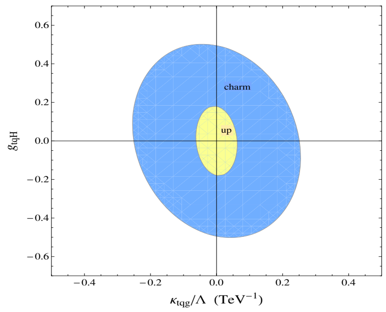


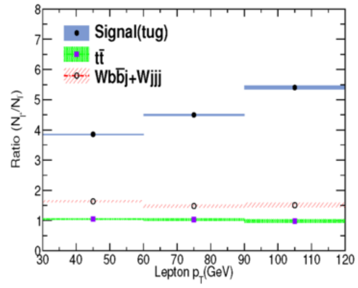
Figure 3: The 3σ exclusion upper limits on the anomalous couplings $\frac{\kappa_{tqg}}{\Lambda}$ and g_{tqH} for 10 fb^{-1} of integrated luminosity at the LHC with 14 TeV.

top rates. This fact is related to the difference between the u-quark and $\bar{u}$-quark parton distribution functions of proton. When top quark decays leptonicly, this asymmetry is translated into a corresponding lepton charge asymmetry. We define a ratio R as the number of events with positive charged lepton to the number of events with negative charge. The inclusive values of R for signal and backgrounds are:

$$\begin{aligned} R_{signal} &= 4.35 \pm 0.02, \\ R_{W+jets} &= 1.57 \pm 0.03, \\ R_{t\bar{t}} &= 1.04 \pm 0.03. \end{aligned} \quad (6)$$

where the uncertainties are only statistical uncertainties. Also, we investigate the dependence of the charge ratio R for the signal and main backgrounds on the transverse momentum and pseudorapidity of the charged lepton. Figure 4 shows the charge ratio R as a function of lepton p_T and lepton η.

As it can be seen in Figure 4 , R grows with increasing the lepton p_T for signal while it is almost flat for backgrounds. This behavior can be understood by considering the fact that the high p_T lepton in the final state needs larger fraction of the parton momentum from the proton PDF. It is well-known that the up quark PDF are much larger than the anti-up quark PDF at large values of x (x is the fraction of the proton momentum which a parton carries). Thus, at large lepton p_T , larger ratio is expected. Also for top pair events the ratio is almost flat and fluctuating around one while for W+jets is very slowly increasing with $|\eta|$. For the signal, R starts from 3.5 at $\eta \sim 0$ and grows significantly up to 6.8 at $2.0 < |\eta| < 2.5$. There is a correlation between p_T and η of the charged lepton for the signal events. According to the Figure 4, it is apparent that the ratio $R(p_T)$ and $R(\eta)$ has a strong discriminating power between signal and the main backgrounds.



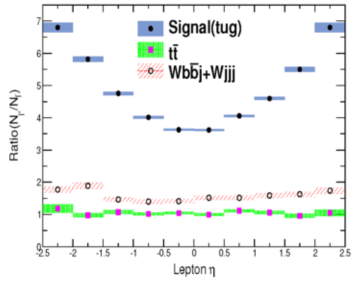


Figure 4: The ratio of positive to negative leptons as a function of lepton p_T and lepton η.

5. Conclusions

In this work we propose to use the $pp \to t(\bar{t}) + H$ process to probe the anomalous tqg and tqH couplings as a complementary channel besides the other channels. We show that the LHC can probe the anomalous $tug(tcg)$ couplings down to 0.01 (0.04) TeV^{-1} with 10 fb^{-1} of integrated luminosity. Also, we propose the charge ratio versus transverse momentum and the pseudorapidity of the charge lepton as a strong tool to discriminate between signal and backgrounds.

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